

REACT: A Rapid Environmental Impact on Airport Community Tradeoff Environment

Dylan J. Monteiro*, Sidharth Prem†, Michelle R. Kirby‡, and Dimitri N. Mavris§
School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA, 30332

Community noise exposure is the one of the key challenges to the potential growth of the aviation industry. Various forecasts have shown that the industry is expected to grow in the future years, and with this comes a predicted increase in noise levels around airports without a significant influx of noise reduction technologies across the fleet. In order to plan for these future scenarios, airports, airlines, the FAA, and local governments must analyze various noise mitigation strategies, operational restrictions, and changes to airport states, whilst still increasing capacity. Thus, it has become important for these entities to be able to rapidly tradeoff different noise mitigation strategies to effectively manage community noise exposure in current and future airport scenarios. However, noise modeling can be a cumbersome task due to the potential for high computational times and its case dependency. Each entity, airport, and community have their own concerns, conditions, and population structure. Current noise modeling software can take multiple hours to set up an airport case study and run a single operational state. REACT, a tradeoff environment developed in this paper, aims to provide the key stakeholders with airport-specific information, an accessible visual user interface, and most importantly, rapid computations. REACT connects the various mitigation strategies and techniques most important to each of the key stakeholders, and allows these authorities to investigate solutions that are most important to them in current and future airport states.

I. Introduction

IN recent years, airport community noise exposure has been declining due to increased precautions, legislation, and technological advancements (both operational and aircraft-based). However, with the predicted increase in demand for air travel, and the higher accessibility to local airports, community noise exposure is forecasted to increase in the future. In fact, airport noise is forecasted to increase by 15% between 2014 and 2035 [1], and with this comes a serious impact on communities around airports. Aviation authorities such as the Federal Aviation Administration (FAA), airports, airlines, and local governments desire a method to rapidly and accurately analyze the varying states at each airport to predict and minimize environmental impacts.

REACT (Rapid Environmental Impact on Airport Community Tradeoff Environment) is a noise modeling tradeoff environment created to handle these issues. REACT aims to create tailored libraries for various global airports and provide pertinent local data to each database. This will reduce an aspect of the long computational times associated with large databases. It also ensures that each community receives the most accurate and relevant data. In addition, REACT aims to provide each of the aviation authorities the mitigation strategies, techniques, and information most important to them. With this rapid modeling technique, decision-makers can quickly and cooperatively make choices around each airport community

II. Motivation

Commercial aviation is one of the major forms of transportation of passengers and cargo in the world. In 2015, airlines transported approximately 3.6 billion passengers around the globe [2]. Furthermore, the air transport industry directly contributes to the global economy, by supporting 3.5% of the world's Gross Domestic Product [3]. Many recent

*Graduate Research Associate, Aerospace Systems Design Laboratory, 275 Ferst Dr., Atlanta, GA 30332, AIAA Student Member

†Graduate Research Associate, Aerospace Systems Design Laboratory, 275 Ferst Dr., Atlanta, GA 30332, AIAA Student Member

‡Senior Research Engineer and Civil Aviation Division Chief, Aerospace Systems Design Laboratory, 275 Ferst Dr., Atlanta, GA 30332, AIAA Member

§Professor of Advanced Aerospace Systems Analysis and ASDL Director, Aerospace Systems Design Laboratory, 275 Ferst Dr., Atlanta, GA 30332, Fellow of AIAA

forecasts have shown that the demand for air travel will increase over the next 20 years, at a rate of 4.3% per year [3]. Therefore, there is the potential for the market to double in the next 15 years.

One of the major issues that airports, airlines, the FAA, and local governments have faced since the onset of commercial air travel has been community noise exposure. Between 1975 and 2000, the number of people exposed to significant noise levels (greater than 65 dB Day-Night Average Level (DNL)) has reduced by approximately 90% [4], due to improved vehicle technology, airspace management, and legislation. However, the number of people residing in areas around U.S. airports with noise levels greater than 65 dB DNL increased from 292,000 in 2010 to 321,000 in 2014 [5]. Moreover, approximately 2.5 million people were exposed to noise levels greater than 65 dB DNL at 45 major European airports [1]. Since the demand for air travel is forecast to increase in the future, the number of people exposed to significant noise levels is also forecast to increase due to the increased number of flights. In the 2016 European Aviation Environmental Report, it was shown that the number of people exposed to significant levels of noise could increase by 15% between 2014 and 2035 [1], if no preventative measures are taken. Therefore, community noise exposure remains one of the key environmental challenges facing the commercial aviation industry.

An important part of the community noise exposure challenge is the impact of the noise on the population surrounding the airports. In this respect, the major concern for airports is the potential population growth around airports, which could be caused by population moving closer to airports. A study conducted by Yuba County Airport in 2007 studied 92 airports in the USA [6]. The study aimed to determine the patterns of growth around airports, find underlying influences of encroachment, and evaluate potential strategies to mitigate land use conflicts. The study looked at land inside the 65 dB DNL (current noise threshold) contour lines and land adjacent to commercial airports. The census metrics showed an interesting trend between DNL values and population/housing changes, as shown in Figure 1. The figure suggests that people are moving closer to airports (higher DNL values tend to be closer to the airport). Hence, population density is increasing near airports. However, the percent changes become considerably smaller as the population near the 65 dB DNL threshold. Furthermore, the study showed that communities around the airports are still being developed; approximately 55% of land adjacent to airports is prone to increased development and population growth. This suggests that as more people move closer to airports, and noise increases in the future, the potential for further communities to be exposed to large amounts of noise increases. Thus, it is very important to consider population changes around airports for any noise mitigation analysis.

	1990 Census Data					2000 Census Data			
	Base Case					Population Change			
	Noise Level	Population	Change	Housing	Change	Population	Change	Housing	Change
1990 DNL	55dB to less than 60dB	7960501		3244569		8895745	12%	3504879	8%
	60dB to less than 65dB	3934228		1601599		4351974	11%	1716089	7%
	65dB to less than 70dB	1484288	NA	593750	NA	1641588	11%	634857	7%
	70dB to less than 75dB	348567		135998		357457	3%	132971	-2%
	75dB +	65723		20944		57472	-13%	17466	-17%
2001 DNL	Noise Change					Population Change			
	55dB to less than 60dB	3706768	-53%	1463514	-55%	4075467	10%	1567868	7%
	60dB to less than 65dB	1141516	-71%	465317	-71%	1236350	8%	483923	4%
	65dB to less than 70dB	309634	-79%	120311	-80%	318188	3%	115785	-4%
	70dB to less than 75dB	61238	-82%	19553	-86%	58983	-4%	18121	-7%
	75dB +	14042	-79%	4996	-76%	12548	-11%	4508	-10%

Fig. 1 Census Data for Various Noise Threshold Levels Averaged Around 90 Airports [6]

There are currently many potential solutions to the challenge of community noise exposure. These solutions range from advanced aircraft concepts, vehicle technologies, improved modeling and planning, and to various operational procedures. The focus of this study is an advanced modeling and planning environment, that will contain elements of all the other potential solutions. Currently, airport noise modeling is a complicated and often a cumbersome task. It is not only restricted by current modeling capabilities, but also by the large number of different stakeholders involved in the decision-making process. Airports currently set up hour-long studies with potential 24 hour run times to understand a single state at an airport. Furthermore, airports are changing and growing through flight tracks, fleet, and operations. Another important aspect is the potential change to the density of the population in the airport vicinity. Thus, it becomes important for airports to tradeoff between these critical variables and understand future scenarios. In addition, several of these variables are controlled by other entities, such as the local government, the FAA, and airlines. Therefore, the

problem morphs into an inter-institutional issue where each entity has their own concerns and goals.

The environment developed by this investigation aims to solve some of those key issues. Ultimately, it could be used by the key aviation authorities to rapidly and parametrically analyze and tradeoff various noise mitigation strategies, and observe the effect on the local airport community. This could aid in the decision-making process for noise abatement planning for future airport scenarios

III. Background

A. Relevant Noise Metrics

There are two major metrics used in the airport noise modeling process. The first is Sound Exposure Level (SEL), and the second is Day-Night Average Level (DNL) [7]. SEL is a single event metric. This means that it measures a single sound event, which in the context of airport noise modeling is a single aircraft departure or arrival event. It is a measure of the magnitude of a time-varying noise event. The SEL of an event is obtained by capturing the time-varying noise signal, and then averaging this signal to a one second period, as shown in Figure 2a. This gives the user an idea of how loud a particular aircraft departure/arrival procedure is on a given flight track. Hence, it does not measure the noise level of an event at any given time, instead it provides an overall measure of the noise level of the entire event. An important characteristic of SEL is that it is A-weighted, where the various frequencies in the time varying signal are weighted to resemble the perception of human hearing. A-weighting emphasizes the mid to high frequency range of human hearing (1,000 Hz to 10,000 Hz), because human ears are more sensitive to this frequency range and humans tend to find sounds in this range more annoying.

The second metric, DNL, is a cumulative event metric, which is a metric that aggregates the noise level of many events (e.g. multiple arrival and departure operations). DNL is a measure of a 24-hour averaged A-weighted sound level. It captures the sound level of multiple events in a 24-hour period, and then adds a 10 dB penalty to aircraft operations at night-time (10 PM to 7 AM), to represent the increased sensitivity of human hearing and annoyance at night-time. A visual representation is shown in Figure 2b.

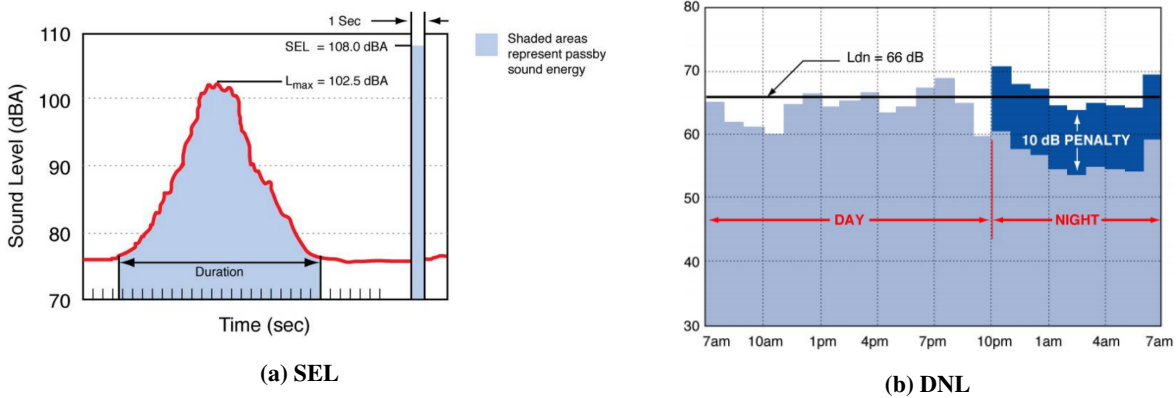


Fig. 2 SEL Metric (left) and DNL Metric (right) [7]

The DNL metric has been identified by the FAA and the U.S. Environmental Protection Agency as the metric used to describe noise levels around airports. There is a correlation between the human annoyance towards a specific noise and the DNL value of that sound event, as illustrated in Figure 3. Thus, this metric provides a link between the physiological and psychological aspects of noise that other metrics may not tend to capture, allowing for a metric that can assess community impact efficiently. Currently, the sound level of 65 dB DNL is the threshold for most legislation, including land zoning and development. This is because it has been shown that at this noise level, a larger percentage of people are annoyed than not annoyed.

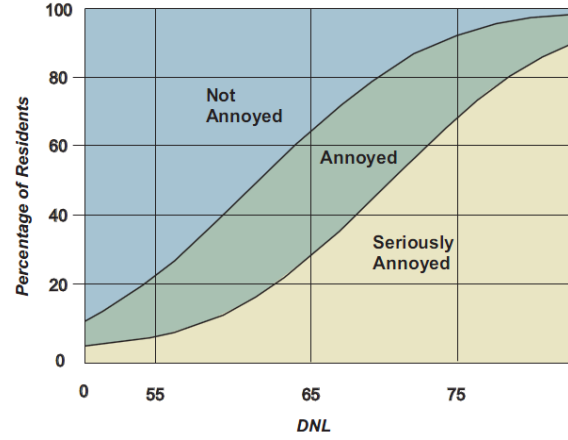


Fig. 3 Relationship between Percentage of Residents that are Annoyed to DNL Level [8].

B. Standard Airport Noise Modeling Procedure

The standard procedure to generate airport DNL contours is outlined in Society of Automotive Engineers Aerospace Information Report (SAE AIR) 1845 [9] and the European Civil Aviation Conference (ECAC) Doc. 29 [10]. It is also illustrated in Figure 4. The metrics described in the previous section are utilized. The process starts with Noise-Power-Distance (NPD) curves per aircraft. These curves provide a relationship between the SEL noise level at points away from the aircraft, at various engine thrust levels. These NPD curves are used to calculate unique departure and arrival SEL grids for each aircraft-engine-runway-flight track combination. NPD curves are typically specified at standard sea-level conditions. Hence, these curves must be corrected to the airport atmospheric conditions when generating the SEL grids. This procedure in real-time tends to be the largest contributor to the high computational times in noise modeling. The SEL grid computations must be done per airport per operation and can take multiple hours of computational time (not including setup and information gathering).

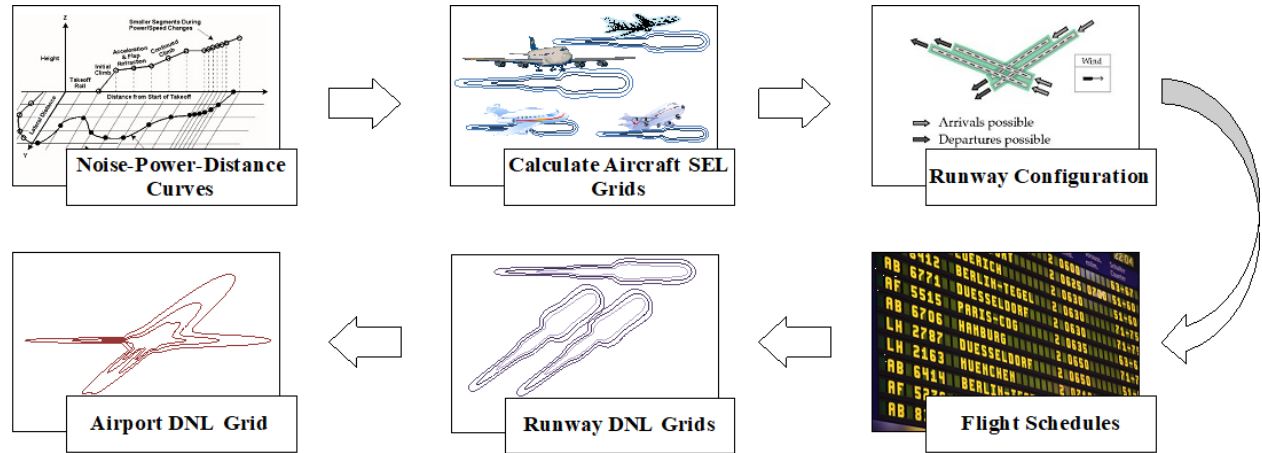


Fig. 4 Flowchart Describing the Standard Procedure for Generating Airport DNL Contours

Once the SEL grids are created, the next step is to generate the airport-level DNL contours. This step utilizes the runway configuration information and flight schedules for a representative day at an airport. The flight schedule contains information regarding the number of aircraft-engine combination operations on the different runways and flight tracks at the airport for a representative day. Aircraft SEL grids are then placed on appropriate runways and aggregated at each runway to form runway DNL grids. The final step becomes to additively cumulate runway DNL grids across the airport to achieve the airport DNL contours. These contours form the basis for the community exposure map for the airport.

C. Current Noise Modeling Software

There are three major noise modeling softwares available at the time of this publication. The first is the Aviation Environmental Design Tool (AEDT) [11]. This tool was developed by the FAA to replace the Integrated Noise Model in 2015. It is used by the US government, US airports, the International Civil Aviation Organization (ICAO), and many other international entities. In the US, AEDT is used to generate the official noise exposure maps for US airports. The second tool is the Integrated Aircraft Noise and Emissions Modeling Platform (IMPACT) [12], which is developed by EUROCONTROL. This tool is very similar to AEDT, but it is focused more on European airports. It is used by many European aviation authorities, and it was also used by the ICAO for the 2016 ICAO Environmental Report [13]. The third software is Aircraft Noise Contour Model (ANCON) [14], which is developed by the UK Civil Aviation Authority. ANCON models a select few British airports, and its database is tailored to these airports.

The relative merits of these programs against key requirements for a noise modeling and simulation environment are compared in Table 1. These requirements were developed from the motivation of this topic, as well as interactions with key stakeholders (airport officials at MCI and DFW, Airlines for America, and the FAA Office of Environment and Energy). The table shows that there are three main requirements that the current modeling software do not meet. These categories are rapid assessment, forecasting ability, and parametric interactivity.

Table 1 Assessment of Current Noise Modeling Software

	Rapid Assessment	Noise Modeling	Emissions and Fuel Burn	Population	Demographics	Forecast	Parametric Interactivity
AEDT	✗	✓	✓	✓	✓	✗	✗
IMPACT	✗	✓	✓	✓	✓	✗*	✗
ANCON	✗	✓	✗	✓	✗	✗	✗

*Fleet forecasting for IMPACT available with AAT package

IV. Technical Approach

The objective of this research was to develop a rapid, parametric tradeoff environment that assesses the environmental impact of various noise mitigation strategies on current and future airport communities. This objective was used to derive the technical approach, presented in Figure 5.

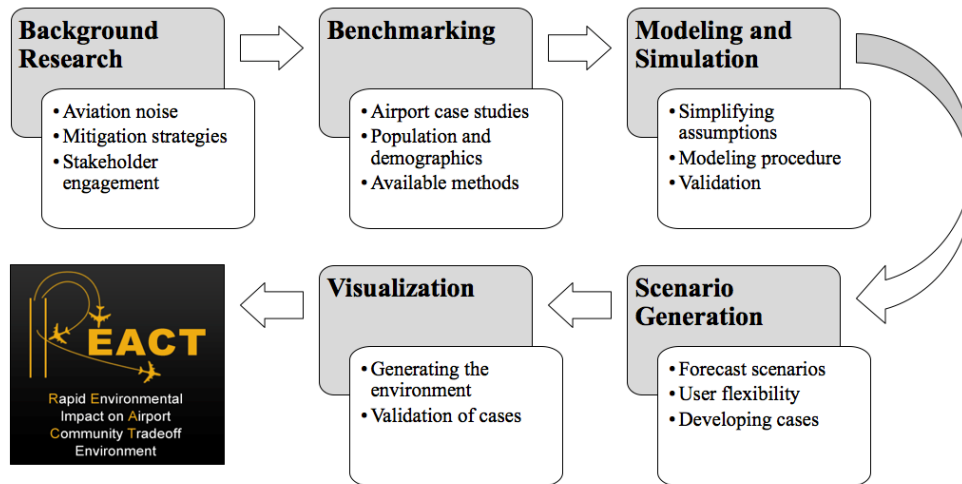


Fig. 5 Technical Approach Flowchart

One of the goals of this tradeoff environment is to be airport-specific, i.e. a tailored database for each airport. Since community noise exposure is a very case-dependent issue, two airports were selected as case studies to build REACT. These two airports were Kansas City International Airport (MCI) and Dallas-Fort Worth International Airport (DFW). MCI is a mid-sized airport with 122,844 operations in 2016 [15], and it ranks amongst the airports with the fewest delays in the US. On the other hand, DFW is the third busiest airport in the world by operations, and had 672,748 operations in 2016 [16]. Two airports of different capacities were selected for two main reasons. The first was to test how the modeling procedure preforms with two airports of different sizes. The second reason was to test the sensitivities of computation time and other various metrics to airport size. Ultimately, REACT hopes to be tested with other airports of various capacities, resulting in a tailored library of airports. However, that is beyond the scope of this investigation.

V. Implementation

The architectural flowchart of the REACT environment is presented in Figure 6. The database module contains all the relevant data for the airport. Since one of the key goals of REACT was for the database to be airport specific, this module of REACT is tailored for each airport, thereby providing an accurate baseline for each airport. The Graphical User Interface (GUI) draws information from the database, and presents the user with the capability to implement various scenarios. The scenarios and other inputs are then transferred to the environmental calculations module, where ANGIM (Airport Noise Grid Integration Method) and GREAT (Global Regional Environmental Aviation Tradeoff) perform the calculations. ANGIM and GREAT are both tools developed at the Aerospace Systems Design Laboratory at the Georgia Institute of Technology under FAA PARTNER/ASCENT funding. An overview of these tools will be presented in Sub-Section G, and further details of these tools can be found in Bernardo et al. [17] [18] [19]. The outputs module takes the outputs of ANGIM and GREAT, and converts them into noise contour maps, and other relevant environmental metrics. These outputs are then displayed in the GUI, and the user can make any changes to the scenario to tradeoff different mitigation strategies.

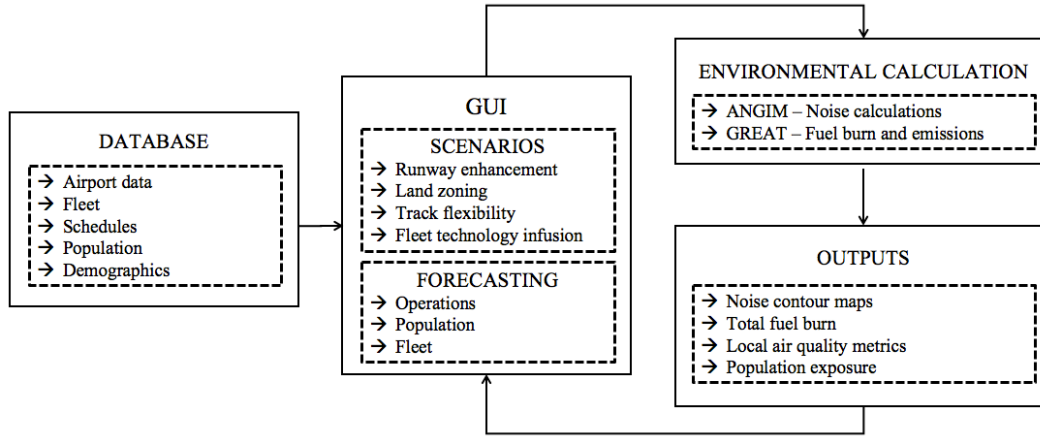


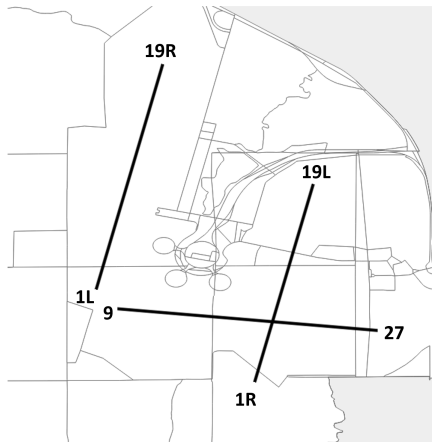
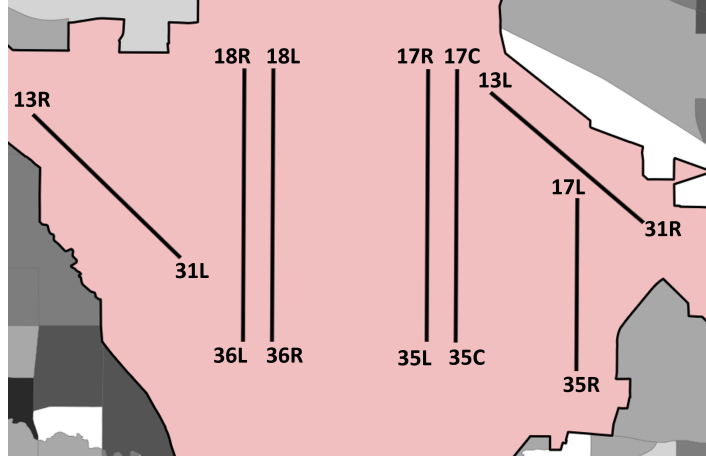
Fig. 6 Flowchart of the REACT Environment

A. Airport Data

One of the main entries in the database is the airport environmental data. This data is unique to each airport and defines some of the most important information for noise calculation, particularly the runway configuration and atmospheric information. The runway configurations are defined by the runway start-point and the runway end-point, expressed as two latitude-longitude coordinate points. However, ANGIM runs its noise contour creator by beginning its coordinate reference frame on a single runway end, which from here on will be referenced as the ANGIM reference frame. For this transformation to be possible, it is also important to have the heading angle that describes the angle of rotation of the reference runway. Thus, to fully understand runway configuration information, it is necessary to know the two coordinate points for the runway ends and the heading angle for each runway with respect to the vertical line. A summary of the required runway information is shown in Table 2, and a visual representation of the runways is presented in Figure 7.

Table 2 Standardized Runway Information

Runway Name	Runway Start [Lat, Long]	Runway End [Lat, Long]	Heading Angle [deg]
–	–	–	–

**(a) MCI****(b) DFW****Fig. 7 Runway Diagrams: MCI (left) and DFW (right)**

The next form of airport data necessary is atmospheric information. This information is vital in calculating SEL noise grids because noise propagation heavily depends on annual average day atmospheric values at the airport [20]. This required information includes runway end elevations, temperatures, SLP pressures (reference sea-level), ST pressures (reference ambient), relative humidity, dew point, and headwind. This data was extracted from the AEDT 2c weather database for the two case-study airports, and the values are based on an average day in 2015. The standard form for this airport data is summarized in Table 3.

Table 3 AEDT Standard Atmospheric Information

RWY Name	RWY Start Elevation [ft]	RWY End Elevation [ft]	Temperature [°F]	SLP Pressure [mbar]	ST Pressure [mbar]	Dew Point [°F]	Relative Humidity [%]	Headwind [kts]
–	–	–	–	–	–	–	–	–

B. Fleet and Operations Database

The fleet and operations database contains information regarding the particular aircraft operating at the airport, as well as the flight schedules. The flight schedules contain information on the number of day-time and night-time operations per unique aircraft-engine combination per flight track/runway. This data was generated based on an average day in 2015 for both case-study airports. Note that for DFW, the schedule was supplemented with data from the Environmental Affairs Department at DFW.

This data was analyzed to determine the baseline operational conditions at both airports. The operations by aircraft class is presented in Figure 8. This figure shows that over 95% of the operations at both airports were commercial operations, implying that the majority of the noise energy stems from regularly scheduled commercial transport aircraft. Furthermore, Figure 9 displays the operations by aircraft at both airports. For MCI, the figures shows that approximately

26% of the operations at this airport were from the Boeing 737-700. In a similar fashion for DFW, the Boeing 737-800 has the most operations at DFW with approximately 18% of total operations. For both airports, the five most utilized aircraft account for around 60% of all operations. This baseline analysis of the fleet operations provided great insight into the fleet operations at the airport, and highlighted the important aircraft for accurate modeling.

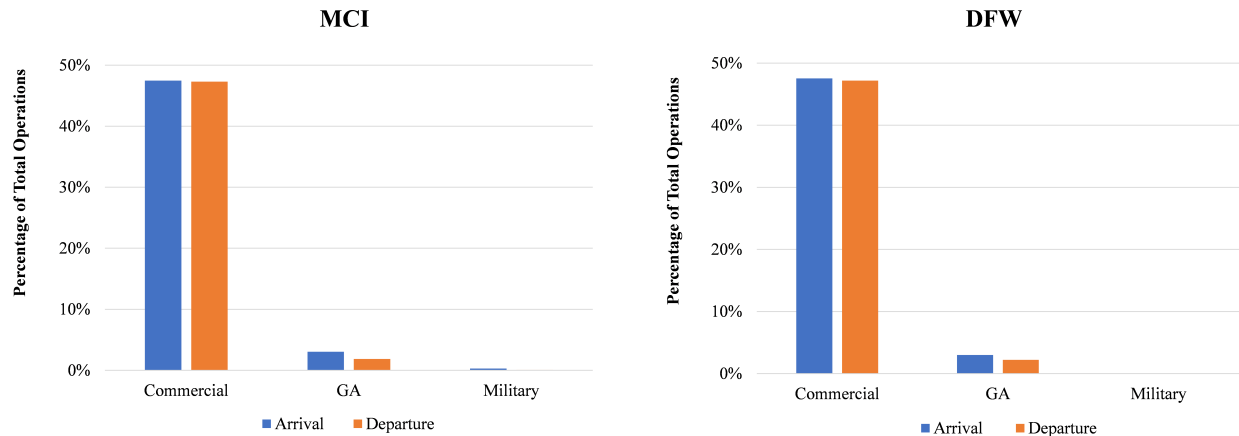


Fig. 8 Operations by Aircraft Class on an Average Day in 2015: MCI (left) and DFW (right)

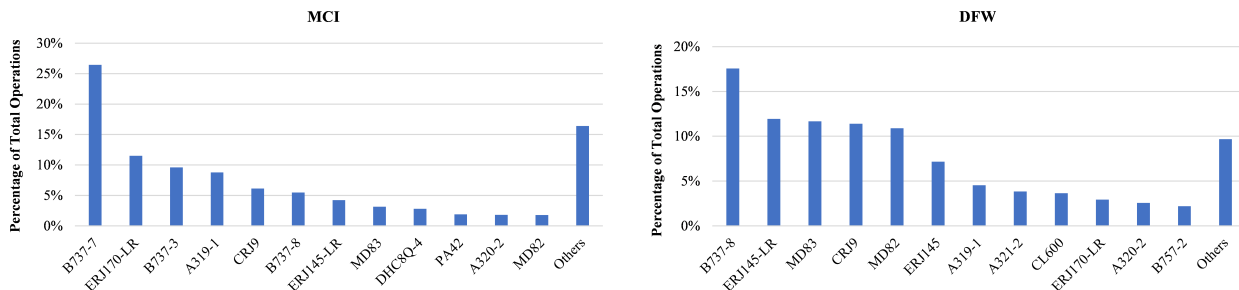


Fig. 9 Operations by Aircraft on an Average Day in 2015: MCI (left) and DFW (right)

Another important task of the baseline analysis was to understand how the airports typically operate on an average day. A runway utilization analysis was performed for both airports, and the results are presented in Figure 10 (Note: refer to Figure 7 for runway diagrams of both airports). For MCI, the figure shows that the preferred traffic direction is North to South. The majority of the departures tend to be on 01L/19R. Typically, one of the parallel runways is used for arrivals, while the other is used for departures. Crosswind runway (9/27) operations account for approximately 16.5% of the total operations. In contrast, the utilization is very different at the larger and more busier airport DFW. At DFW, the majority of departures are on the inner parallel runways (17R/35L and 18L/36R) and the majority of arrivals are on the outer parallel runways (17C/35C and 18R/36L). The figure infers that the airport is typically split into an East half and a West half, and both halves have an arrival and a departure runway operating simultaneously. This is how the airport handles large volumes of traffic during peak operating hours. There are also some unique runways at DFW. One of these is 17L/35R, which is an arrival-only runway. Another example is 13L, since jet departures are prohibited on this runway. The runway utilization at these two airports are very different, which further supports the claim that each airport should be analyzed individually.

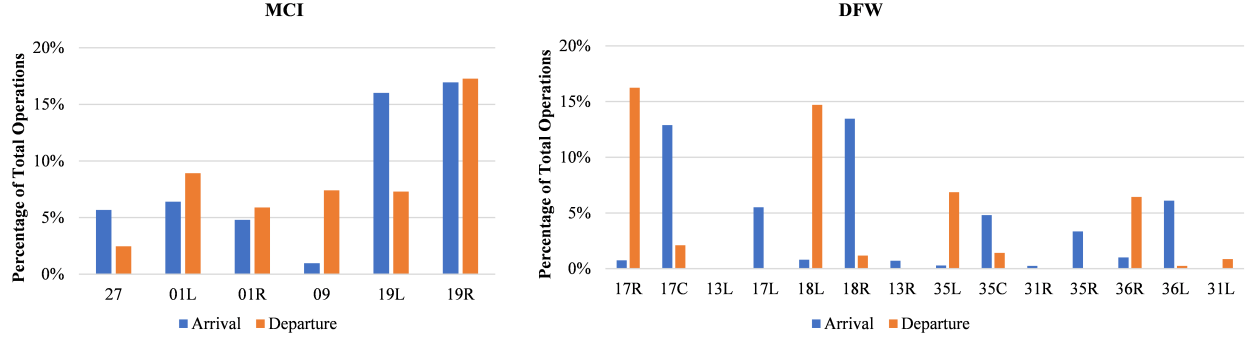


Fig. 10 2015 Average Day Runway Utilization: MCI (left) and DFW (right)

C. Operations Forecasting

For REACT, the method that was selected to forecast airport operations was the FAA Terminal Area Forecast (TAF) 2015 model [21]. This is the official forecasting method for all US airports, and it predicts commercial, general aviation, military, and commuter operations. Figure 11 presents the historical and forecasted operations for both airports. The figure shows that the trend for the forecasted operations at DFW closely follows the trend of the operations in the past five years. However, for MCI, the operations have been declining over the past five years, yet the TAF still predicts an increase in operations in the future. The main reason that the operations have been declining at MCI is that airlines are using larger aircraft to accommodate the same number of people. In fact, the annual volume of passengers has been increasing at MCI. For the current version of REACT, the user was presented with two discrete forecast years of 2020 and 2030. Each forecast-year had three discrete demand scenarios: a nominal TAF scenario, a high-demand scenario (2% greater than the nominal TAF for that year), and a low-demand scenario (2% lower than the nominal TAF).

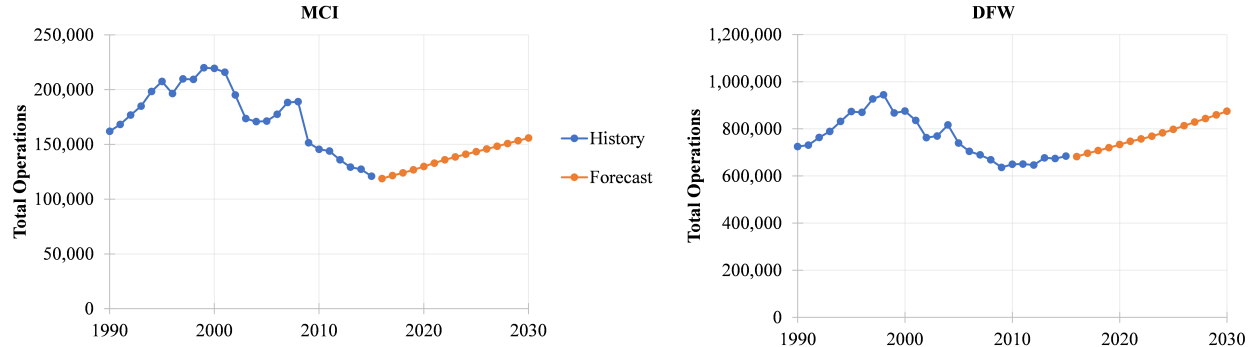


Fig. 11 Airport Historical Operations and FAA TAF Data: MCI (left) and DFW (right)

D. Flight Track Parameterization

When creating an environment with the potential capability for flexible flight tracks, it was important to develop a scheme that enables flight track definition based on a set of parameters. AEDT defines flight tracks based on a set of coordinated points that are calculated based on five segments, with a total of nine parameters [22]. This flight track parameterization scheme was adopted for REACT.

The segments and the associated variables used in the track parameterization are shown in Figure 12. The first segment is a straight segment from the brake-release point to a fixed point defined by the length L_1 . The second segment is a turn, which is defined by three parameters; the direction of the turn (left or right) is fixed by T_1 , the radius of the turn is defined by R_1 , and the degree of the turn is given by θ_1 . The third segment is a straight segment tangent to the curves, and characterized by the length L_4 . The fourth segment is another turn prescribed by the same three parameter types as turn 1 (T_2 , R_2 , θ_2). The fifth and final segment is also a straight segment tangent to the turn, and it is defined by the length L_6 . This vector track definition was then converted into a coordinate form, which was used to generate the shape-files that are displayed in the GUI.

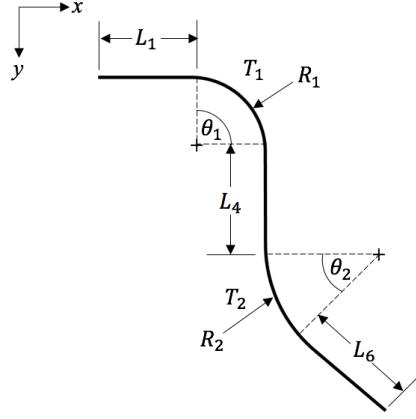


Fig. 12 Flight Track Segmentation and Parameterization

E. Population Database and Forecasting

The baseline population densities for the MCI and DFW areas were obtained through the 2010 US Census data from the US Census Bureau, and this data is presented in Figure 13. This data was chosen because the data could be extracted to the highest resolution, which was the census county block level. Therefore, this enabled the user to review how many people are living in different blocks and neighborhoods around the airport. Thus, the user could visualize the number of people exposed to high noise levels around an airport at a high resolution, and accurately pinpoint noise sensitive areas.

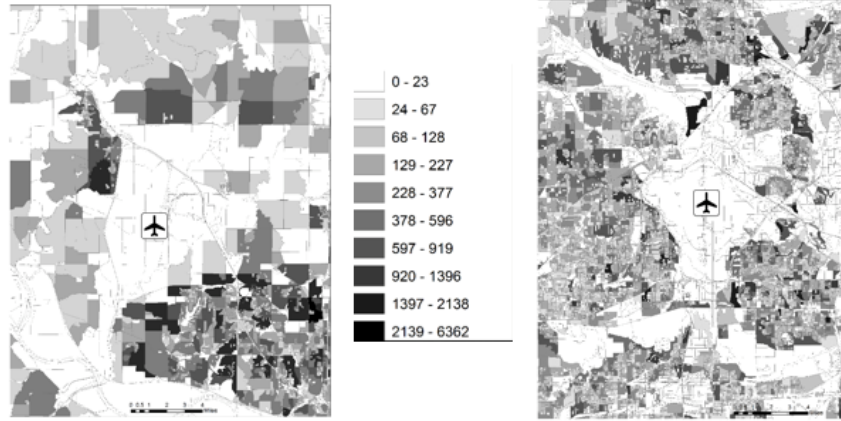


Fig. 13 2010 Census Baseline Population Blocks for MCI (left) and DFW (right)

One of the main goals of REACT was to provide a forecasting capability for both operations and population. There were two methods explored for population forecasting. The first was the Cohort Component Method [23]. This is the official method used by the US Census Bureau for population forecasts. One of the key benefits of this method is that it allows for the analysis and forecasting capability over a large range of data. Hence, it is very good for large scale population forecasts. However, this led to the biggest drawback of this method. It is very difficult to access the data necessary to implement the forecast over a small area. Therefore, it isn't feasible to use this method to forecast the population at the resolution of the census block level.

The second method was the Ratio Based Postcensal Small Area Projections method [24]. This is a derivative of the Cohort Component method and it is used by the US Census Bureau for population projections of counties or other small areas. It uses the ratio of the population of the various census blocks to the overall region population, to predict the change in population at the county block level. Hence, it is the ideal method to predict the population growth of the individual census blocks, and thus it was the method chosen to forecast population for REACT. The values for the forecasted population in the MCI and DFW areas are shown in Table 4, and further details of this method can be found in the report by GIS Associates, Inc. [24].

Table 4 MCI and DFW Population Forecasts

Airport	2010 Census Population	2020 Predicted Population	2030 Predicted Population	Average Growth per 10 years
MCI	2,414,872	2,633,223	2,850,370	8%
DFW	6,784,803	8,504,463	10,926,663	27%

F. Noise Mitigation Strategies

Due to the complex and case-dependent nature of airport noise, there are many different noise mitigation strategies employed at various airports. The majority of these mitigation strategies can be categorized into six categories: land planning, regulations and guidelines, ground mitigation, operational restrictions, flight procedures, and community engagement.

Land planning consists of the management and zoning of the land around the airport. This is where the local government sections certain areas of the land around the airport for particular uses, e.g. one zone for industrial use only, and another zone for residential use. In the majority of cases, the DNL noise contours drive some of the land zoning, in an effort to minimize the number of people exposed to high levels of airport noise.

The second mitigation strategy, regulations and guidelines, include Federal Aviation Regulations (FARs) as well as voluntary studies. The FAR Part 36, adopted from ICAO Annex 16 Volume 1, is the primary regulation for the noise certification of aircraft, and it specifies maximum noise levels for certified aircraft as a function of take-off weight [25]. Aircraft manufacturers must adhere to these regulations. Furthermore, there are also voluntary airport-level Chapter 14 CFR (Code of Federal Regulations) Part 150 studies [26]. These are airport noise compatibility studies, which provide the participating airport with updated noise exposure maps every few years, as well as guidelines and suggestions on reducing the noise exposure at the participating airport. Part 150 studies also identify areas of land that are compatible with various levels of noise exposure, and provide technical assistance to airports and local governments on the analysis and execution of the noise compatibility program. Out of the two case study airports, MCI participated in a Part 150 study in 2009 [27], and it receives updated noise exposure maps every five years, and updated noise compatibility programs every ten years.

Ground mitigation and operational restrictions are the third and fourth general categories for noise mitigation strategies. Ground mitigation strategies include engine run-up restrictions, APU restrictions, and reverse thrust restrictions. Both case study airports employ these strategies. For example, both airports have designated engine run-up areas. Operational restrictions include preferential runway programs, departure prohibited runways, and night-time operational restrictions/quotas. Since it is a very high volume airport in a metroplex, DFW employs a variety of operational restrictions, an example of which is the prohibition of jet departures on certain runways shown in Figure 10 on page 9.

Flight procedural noise mitigation strategies consist of Noise Abatement Departure Procedures (NADPs), satellite based navigation (FAA NextGen), and smart flight track definition. Both case study airports employ NADPs. Furthermore, DFW implemented FAA NextGen Area Navigation (RNAV) departure and arrival procedures in the 2000s. This significantly decreased the widths of the departure and arrival tracks at the airport, as illustrated in Figure 14. This implementation increased the departure throughput by 14% [28]. While RNAV was not implemented as a noise abatement procedure, it did have a significant benefit in terms of reducing community noise exposure. The precise flight tracks reduced the population exposed to noise levels of 65 dB DNL by 22% [28].

One of the most important noise mitigation strategies from an airport point-of-view is community engagement. Both DFW and MCI have an efficient system for accepting and responding to noise complaints. Furthermore, through community outreach and education, the airports keep the community updated on any potential changes to the airport. This is vital in maintaining strong relationships between the airport and the surrounding community. A rapid and parametric tradeoff environment, such as REACT, could aid in the community engagement process, by enabling airport authorities to show the community the effects of various scenarios in a quick and visual manner.

Noise mitigation strategies are used by different entities, depending on the particular case. For instance, landing planning is a technique primarily used by the airports and local governments. Similarly, the airlines are affected by flight procedures, and regulations and guidelines are primarily defined by the FAA. Many of the general strategies, such as regulations and guidelines, were difficult to implement directly into noise modeling environment. Thus, when considering strategies for REACT, a sub-set of the noise mitigation strategies were chosen, in order to meet the needs of

the various stakeholders. These strategies were chosen from background research of the two airport case studies, as well as direct interactions with the key stakeholders. In summary, REACT created strategies for land planning through population block density control, operational changes through forecasted years, flight procedural changes through track flexibility, and fleet technology insertions to simulate technology advancements. These strategies, along with community engagement, were considered to encompass most of the priorities and concerns of the stakeholders invested in community noise exposure.

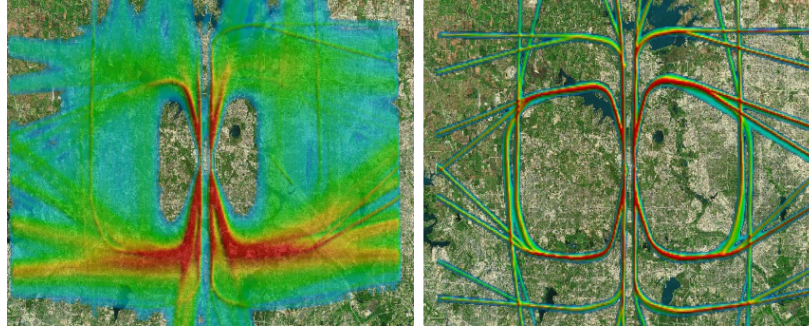


Fig. 14 DFW Flight Tracks without RNAV (Left) and with RNAV (Right) [28]

G. Environmental Calculations

For the environmental calculations module in the REACT flowchart presented in Figure 6, there were three options for the modeling and simulation tools. The first was AEDT, which was developed by the FAA and is the tool used to generate official noise contours in the US. It can also calculate terminal area fuel burn and emissions. However, one of the largest drawbacks of AEDT is that it has relatively high computational times to set up an airport study and generate noise contours. Therefore, it did not meet one of the key requirements of rapid calculations for REACT. Nonetheless, AEDT was still used as a benchmark, to compare how close the noise contours generated in REACT were to the official noise contours.

The other two tools were introduced in Figure 6 as ANGIM and GREAT. ANGIM is a tool that rapidly generates airport-level DNL contours from a flight schedule and aircraft-level SEL contours. It also computes metrics such as contour dimensions, and population exposed. GREAT is a tool that calculates terminal area emissions and fuel burn at an airport-level, based on the fleet data set. The capabilities of these tools are summarized in Table 5. It shows that while ANGIM and GREAT individually both provide rapid assessment, they do not meet all of the requirements as stand-alone tools. However, combining ANGIM and GREAT together yields a modeling and simulation environment that meets all the requirements. Detailed description of ANGIM and GREAT can be found in Bernardo et al. [17] [18] [19]. At the time of this publication, only the ANGIM module in REACT was developed and integrated, and the GREAT module was not yet integrated.

Table 5 Comparison of Modeling and Simulation Options for REACT

Available Tools	Rapid Assessment	Noise	Emissions and Fuel Burn	Population	Demographics	Forecasting
AEDT	✗	✓	✓	✓	✓	✗
ANGIM	✓	✓	✗	✓	✓	✗
GREAT	✓	✗	✓	✗	✗	✓
ANGIM + GREAT	✓	✓	✓	✓	✓	✓

The methodology used to generate airport-level DNL contours using ANGIM varies slightly from the standard airport noise modeling procedure shown in Figure 4. The modified procedure is shown in Figure 15. The main difference is that the SEL grids were pre-computed for each unique aircraft-engine-track combination at each airport. The standard procedure calculates aircraft SEL grids from noise-power-distance curves in real-time, which is very computationally

expensive, since the procedure involves correcting for the atmospheric conditions as well as computing these grids for every unique aircraft-engine-track combination in real time. However, REACT was built as a case-dependent analysis tool. Therefore, the unique aircraft-engine-track combinations were identified for each airport and stored in the operations database. An example of the identifier for an aircraft-engine-track combination is "B737-8_4CM042_DJ24", which signifies the SEL grid of a Boeing 737-8 with the 4CM042 engine code flying on departure track J24. The average atmospheric conditions at each airport were also determined as part of the airport environmental data set. Therefore, it was possible to pre-calculate the aircraft SEL grids for each airport, thus saving computational time and memory. When the user generates an airport-level DNL contour, the REACT environment simply calls ANGIM, which aggregates the relevant SEL grids through the process shown in Figure 15. This process takes a matter of minutes, as opposed to the hours that might be required for more high-fidelity noise modeling programs.

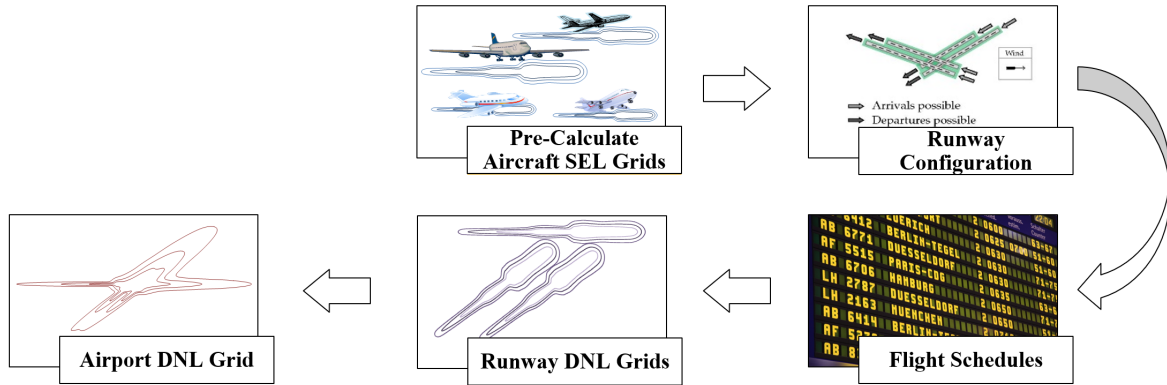


Fig. 15 Modified Noise Modeling Procedure for ANGIM that was utilized in REACT

The pre-computed SEL noise contours were computed using the Noise-Power-Distance (NPD) curves for a particular aircraft-engine combination. These curves provide a relationship between the SEL noise levels at points away from the aircraft, at various engine thrust levels. The AEDT Tester high-fidelity model was used to compute these SEL grids. The AEDT Tester is a program developed at the Aerospace Systems Design Laboratory at the Georgia Institute of Technology[29]. It utilizes the AEDT Aircraft Performance Module, AEDT Aircraft Acoustics Module, and AEDT Aircraft Emissions Module to compute the performance of a particular single aircraft event. It has the capability to generate SEL grids for any flexible flight track, which was used to pre-compute the SEL contours for the pre-defined alternate flight tracks for REACT. Furthermore, the AEDT Tester utilizes the NPD curves for a particular aircraft, which are typically specified at standard sea-level conditions. Hence, it corrects these curves to the airport atmospheric conditions when generating the SEL grids. Further details regarding the AEDT Tester can be found in LeVine et al. [29].

One of the main factors that determines the ANGIM computation time for the generation of airport-level DNL contours is the total number of SEL grids. Therefore, it was important to minimize the number of unique SEL grids for each airport, and thus there were some simplifying operational assumptions made. The purpose of these assumptions was to reduce the computational time, without losing any accuracy in the calculations. The operations by aircraft were analyzed at both airports, to capture the most significant and consistent contributors to the noise levels, whilst capturing at least 90% of the operations at the airports. It was found that by excluding general aviation, military, business, and turboprop operations, the analysis was still able to capture at least 90% of the operations, as shown in Figure 16. Based on the data-set for an average day in 2015, the excluded operations only accounted for 8.7% of total operations at MCI and 6.2% of total operations at DFW.

Within the commercial jet operations, further simplification was carried out by combining very similar aircraft operations together. Based on prior experience and analysis at the Aerospace Systems Design Lab, it was found that many aircraft (particularly variants of the same model) have almost identical noise signatures in terms of NPD curves. This combination was only performed if a variant aircraft had a negligible amount of operations, relative to a baseline model. For example, the Boeing 737-300 had far more operations than the Boeing 737-400 at MCI. Hence, the Boeing 737-400 operations were combined with the Boeing 737-300 operations, and the Boeing 737-300 aircraft was used to generate SEL grids. The primary reason for the combination was the minimization of the number of unique SEL grids, which saves computation time and memory.

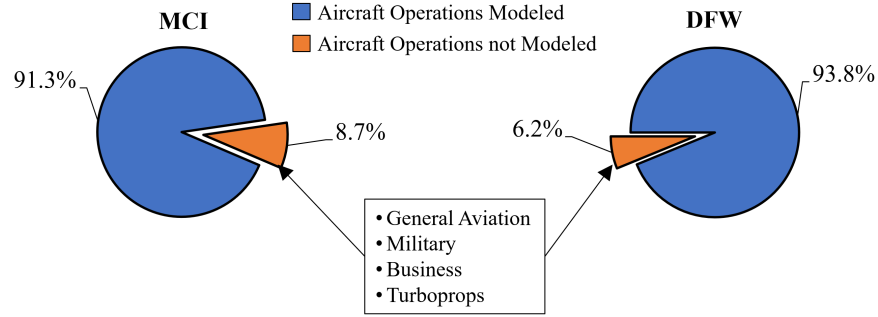


Fig. 16 Percentage of Operations Modeled in REACT for MCI (left) and DFW (right)

Moreover, reducing the number of tracks modeled also reduces the number of SEL grids, hence reducing the computation time of ANGIM. The operations by track were also analyzed at MCI and DFW, in order to capture the prevailing tracks that are used for commercial jet operations. It was found that once the operations from Figure 16 were removed, there were some tracks at both airports that did not have any commercial jet operations. These tracks are shown in Figure 17 in blue, and they signify military/general aviation flight tracks. Therefore, the tracks in blue were removed, and the final flight tracks that were modeled for both airports are shown in yellow in Figure 17.

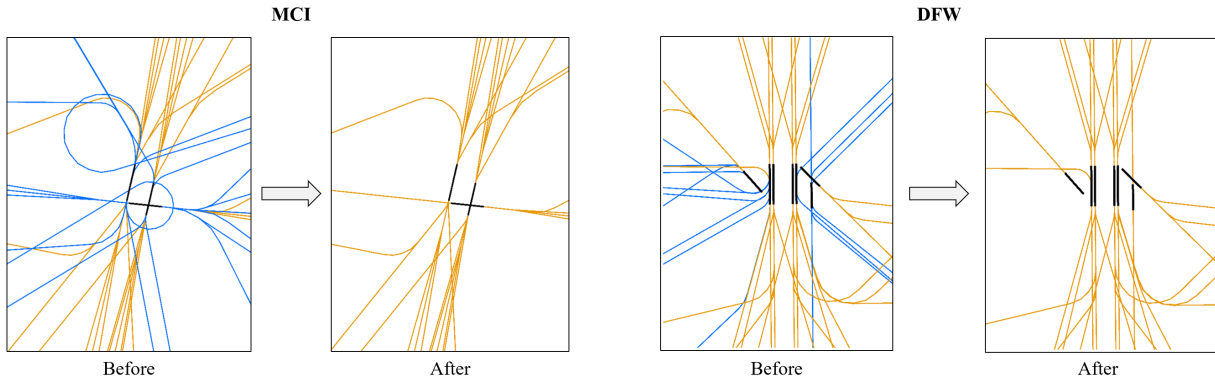


Fig. 17 Change in the Number of Flight Tracks after Operational Assumptions for MCI (left) and DFW (right)

VI. Results

A. Noise Contour Validation

The airport-level DNL contours that were generated using REACT with the simplifying assumptions were compared to the AEDT baseline contour of the same average day in 2015 with the full operational and track set. The resulting contour comparisons are shown in Figure 18 for both airports. In general, the REACT contour shape is very similar to the baseline AEDT shape for all three decibel levels, and the contours took approximately 90 seconds to generate. The difference in contour area was less than 10% overall, which is acceptable given the savings in computation time and memory. The comparison figure suggests that there were more contour differences for the MCI case than the DFW case. One reason for this might be that a larger portion of the total operations were not modeled for MCI (8.7% not modeled) compared to DFW (6.2% not modeled), as shown in Figure 16. Another reason could be the difference in the shape of the departure flight tracks between the two airports. This difference implies that relatively high-volume airports are relatively insensitive to the modeling procedure, whereas the mid-sized airports might be more sensitive. Nonetheless, the overall contour shapes are very similar, hence the noise contour generation procedure for REACT was validated, and it can be inferred that REACT accurately captures the noise contours at these two airports.

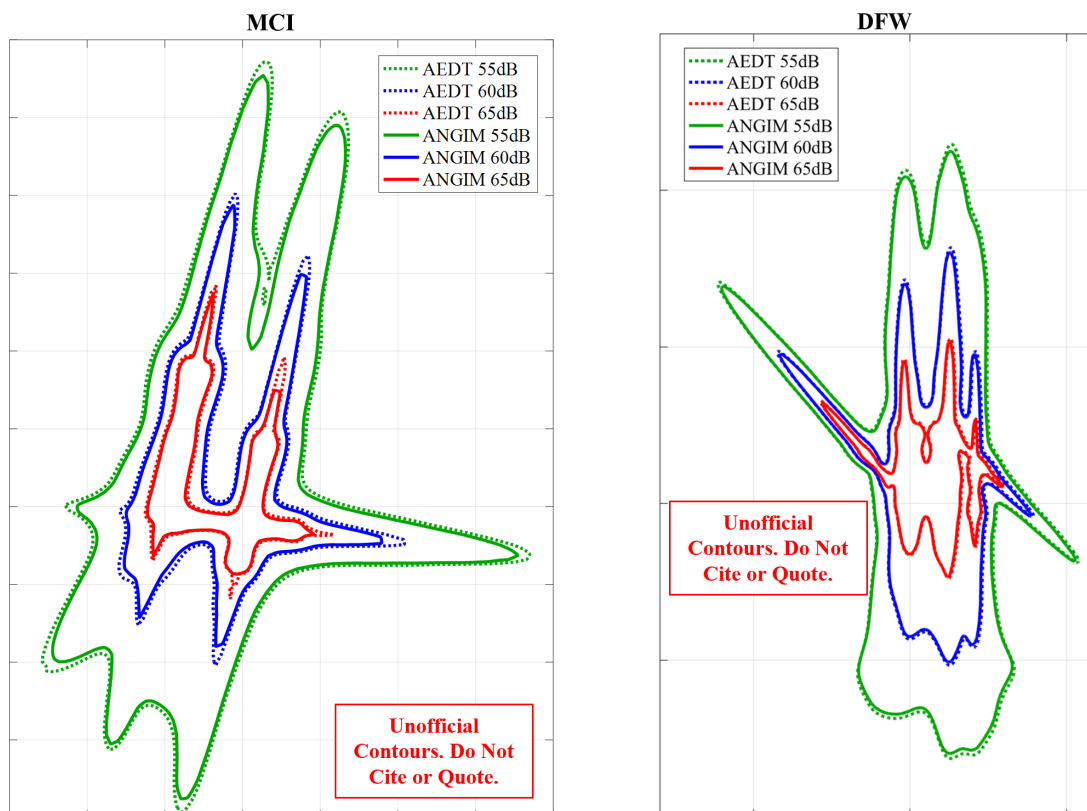


Fig. 18 Comparison of Noise Contours from REACT and AEDT for MCI (left) and DFW (right) Based on an Average Day in 2015

B. The REACT Environment

The REACT environment was written using the ArcGIS for Developers SDK for Java version 10.2.4. The main component of the SDK that was utilized was the Geodatabase Feature Service. Geodatabase files for the population to the block level, flight tracks, noise contours, and runways were used to create the GUI window. These are painted as Feature Layers in the JMap function and the user can directly interact with and modify values within the feature attributes. The main REACT window *Map* tab is shown in Figure 19. Here, the user can view the airport layout, population, and current DNL contours.

The second tab in REACT is the *Database* tab, and an example is shown in Figure 20. The flight schedule is presented in this tab, with information on the number of day-time and night-time operations for every unique aircraft-engine-track combination at the airport. Note that the operations are annualized to represent an average day in 2015. In this tab, the user can also filter the flight schedule by a particular field, and also sort by any of the columns.

In order to create a new scenario to generate a noise contour, the user can navigate to the *Scenario Toolbox* on the main *Map* tab. This is shown in Figure 21. Here, the user can select the forecast year (2020 or 2030), as well as the operational demand scenario for the year (high, nominal, low demand). There are various mitigation strategy simulations in REACT. The user can simulate land zoning, as shown in Figure 22, by directly interacting with any of the population blocks. This would enable the user to implement any potential land planning changes, and observe the impact on the population exposed to airport noise at the various DNL levels. The user can also simulate fleet technology insertions that add a percentage reduction in noise generated by a particular aircraft. The percentage noise reduction can be based on a technology implemented to the aircraft (e.g. a hush kit), or the replacement of a particular aircraft with the next generation quieter version (e.g. replacing A320 with A320-neo).

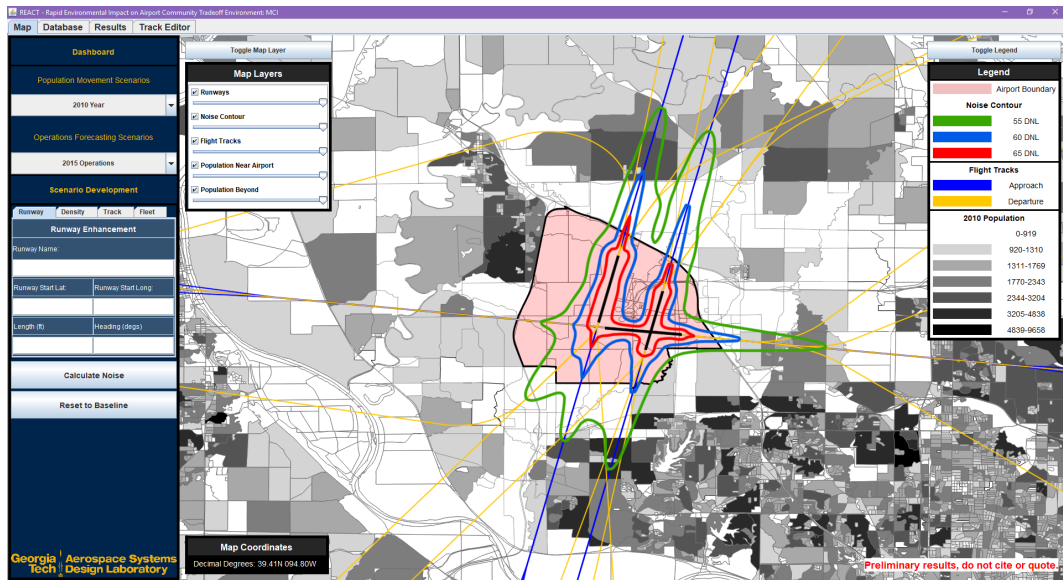


Fig. 19 REACT Main Window Map Tab

FLIGHT SCHEDULE

Filter table by: Aircraft

Aircraft	Track Name	Runway	Operation	Daily Day-Time Operations	Daily Night-Time Operations	Daily Total Operations
Airbus A300F4-600	A2	01L	Arrival	0.03844	0.01778	0.05621
Airbus A319-100	A2	01L	Arrival	0.65129	0.07800	0.72929
Airbus A320-200	A2	01L	Arrival	0.23068	0.02674	0.25741
Airbus A340-600	A2	01L	Arrival	0.00068	0.00019	0.00087
Boeing 717-200	A2	01L	Arrival	0.11749	0.01203	0.12952
Boeing 727-200	A2	01L	Arrival	0.00570	0.00129	0.00699
Boeing 737-300	A2	01L	Arrival	0.72834	0.11063	0.83896
Boeing 737-700	A2	01L	Arrival	2.31620	0.33960	2.65580
Boeing 747-200	A2	01L	Arrival	0.00062	0.00011	0.00072
Boeing 757-200	A2	01L	Arrival	0.13172	0.02067	0.15239
Boeing 757-300	A2	01L	Arrival	0.00166	0.00020	0.00186
Boeing 767-300	A2	01L	Arrival	0.00936	0.00179	0.01116
Boeing 787-800 Dreamliner	A2	01L	Arrival	0.00079	0.00008	0.00087
Boeing DC-10-10	A2	01L	Arrival	0.03970	0.02854	0.06824
Boeing DC-9-30	A2	01L	Arrival	0.00915	0.00212	0.01127
Boeing MD-11	A2	01L	Arrival	0.01861	0.01577	0.03439
Boeing MD-83	A2	01L	Arrival	0.36978	0.04001	0.40980
Boeing MD-90	A2	01L	Arrival	0.17179	0.01819	0.18999
Bombardier CRJ-900	A2	01L	Arrival	0.51221	0.06569	0.57790
Embraer ERJ145-LR	A2	01L	Arrival	0.39841	0.05216	0.45057
Embraer ERJ170-LR	A2	01L	Arrival	0.87930	0.12164	1.00095
Embraer ERJ190	A2	01L	Arrival	0.01179	0.00162	0.01341
Airbus A300F4-600	A2A	01L	Arrival	0.02938	0.01297	0.04235
Airbus A319-100	A2A	01L	Arrival	0.48503	0.05910	0.54413
Airbus A320-200	A2A	01L	Arrival	0.47470	0.03026	0.50496

Fig. 20 REACT Database Tab and Flight Schedule

Another mitigation strategy that was implemented in this version of REACT was the simulation of flight track flexibility. The user can interact with the current baseline tracks, as shown in Figure 23. At the time of this publication, each departure track has a set of five pre-determined alternate tracks. Once an alternate track is selected, the operations from the baseline track are transferred to the new track. Each alternate track also has pre-calculated grids for every unique aircraft-engine combination, hence there is no computation of the SEL grids in real-time. These alternate tracks were determined by varying the track parameters, and the goal was to create a set of tracks that would fly over the smallest number of people. However in reality, there are many more constraints to alternate flight tracks that were not considered in this investigation, such as airspace constraints, aircraft performance limitations, as well as geographical constraints. Nevertheless, the alternate tracks were developed as a proof-of-concept to test the capability of simulating scenarios with alternate tracks. There is a desire to expand this capability to include complete track flexibility with surrogate modeling of the SEL grids based on the track parameterization scheme, however that is beyond the scope of this investigation.

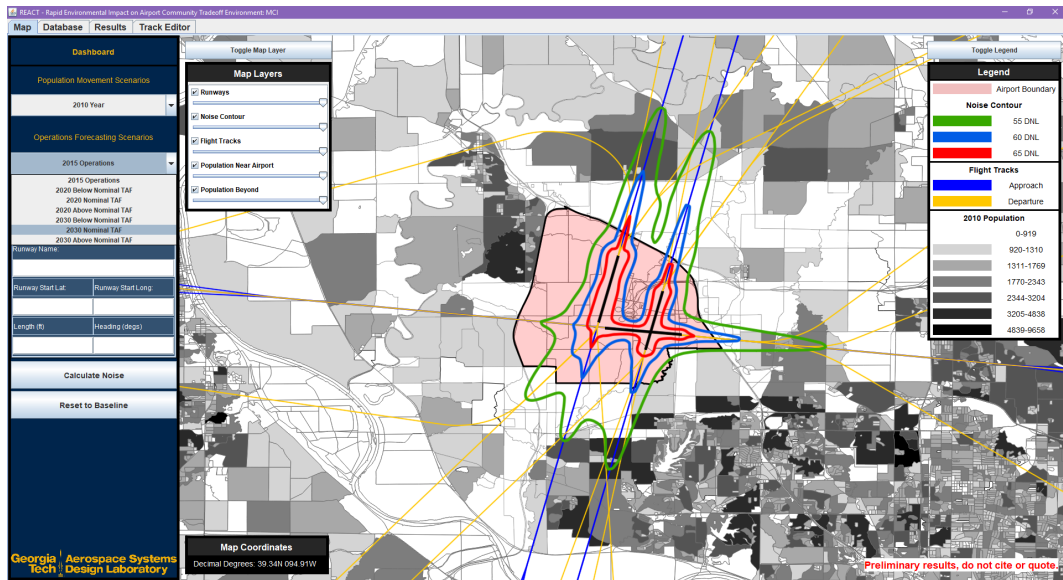


Fig. 21 Creating a Forecast Scenario in REACT

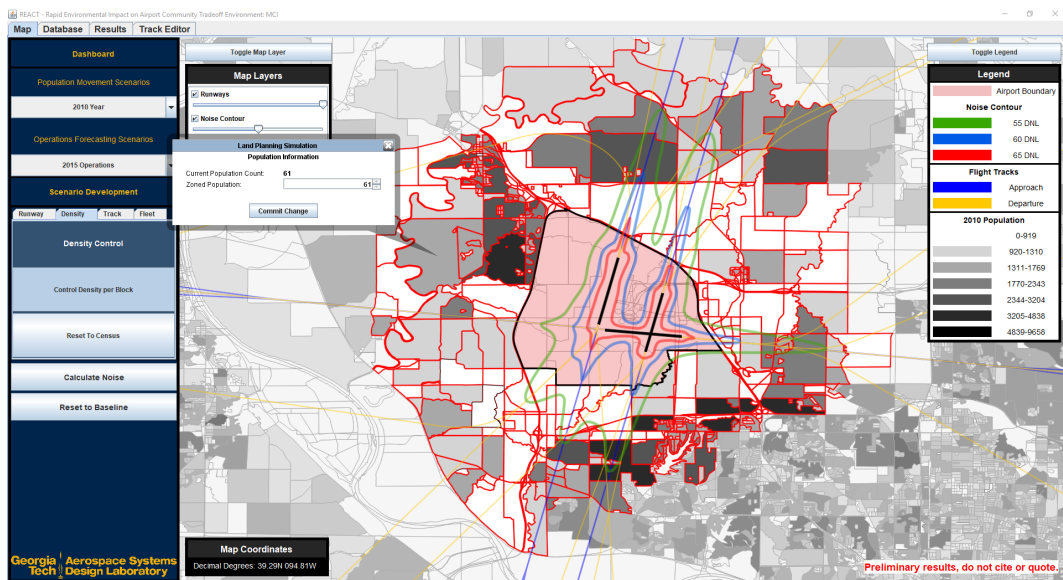


Fig. 22 Land Zoning Simulation in REACT

Finally, the user can run the simulation and view the updated noise contour in the *Results* tab, as presented in Figure 24. A comparison of the new scenario noise contour to the baseline noise contour is presented on this tab. A table of contour metrics is also shown, with the updated contour areas and population exposed for the new scenario. Furthermore, there is a *Scenario Summary* feature that summarizes what the forecast scenario was, as well as what mitigation strategies were employed for this particular case. At the time of this publication, the fuel burn and emissions calculations from GREAT were not integrated, hence there are no results for those particular outputs.

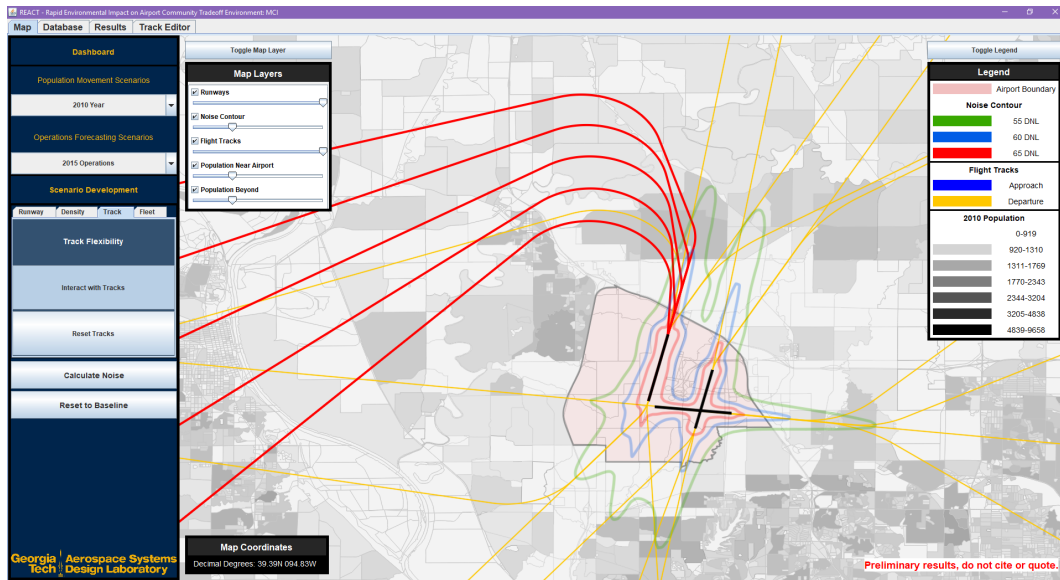


Fig. 23 Selecting an Alternate Track in REACT

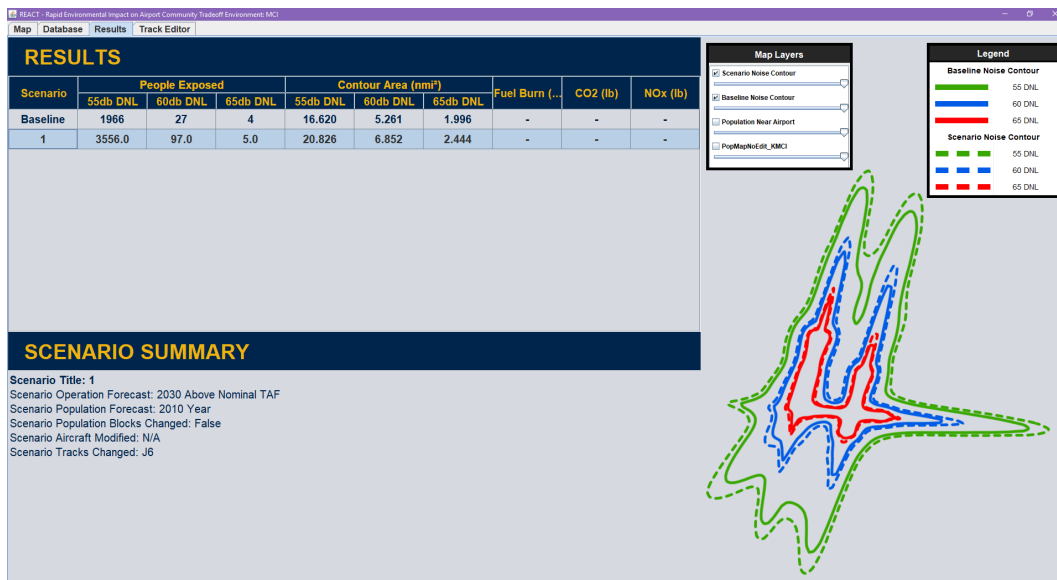


Fig. 24 REACT Results Tab

VII. Conclusion

One of the key challenges that needs to be considered when planning for future aviation growth is community noise exposure. Due to the projected demand increase for commercial air travel, there is also a projected increase in the noise levels around airports if no measures are taken. In order to plan for these future scenarios, and minimize the community impact, it becomes important for the key aviation authorities to rapidly observe the impact of various noise mitigation strategies on the airport community. This enables the authorities to tradeoff these strategies and plan for future airport scenarios.

This research developed the REACT environment, which allows key stakeholder to visualize what-if scenarios at a particular airport. It provides the user with a visual and interactive method of assessing the potential changes to the noise scenario at the airport. REACT was developed as an airport-specific tradeoff environment because noise is a very case-dependent issue, and therefore the database was tailored for two case study airports (MCI and DFW). It has a

focus on the population exposure, with the capability to predict the change in operations and population in the future. Furthermore, the streamlined noise contour calculations result in airport-level DNL contour generation times of a few minutes, as opposed to hour-long studies from other airport noise analysis tools. The REACT contours were validated for MCI and DFW against baseline AEDT contours, and results showed that the accuracy of AEDT was maintained for a fraction of the computation time.

While this research developed the framework for REACT, there are many areas for future work. One of the main areas for future work is to integrate the fuel burn and emissions calculations from GREAT into REACT, thus providing a full set of environmental impact outputs. Moreover, the database can be expanded to include a tailored library of airports of various sizes. There is also scope to add alternative noise metrics in the calculations, such as a track excursion noise metric. Furthermore, the current calculations only account for flight operational noise, but there is the possibility to account for complex noise modeling variables such as wind, ground noise, and thrust reverser noise. The demographic information can also be integrated into REACT. Currently, there are only a discrete set of alternate tracks. However, there is the possibility of implementing full track flexibility, by creating physics-based surrogate models of the SEL grids and track parameters. Finally, there is also the possibility of including other mitigation strategies and growth scenarios, such as runway utilization changes, and the addition of new runways.

Ultimately, REACT provides a way for users to rapidly tradeoff noise mitigation strategies at an airport, and observe the impact on current and future states of the airport community.

Acknowledgments

The authors would like to thank Dr. Matthew LeVine, Dr. Dongwook Lim, Dr. Yongchang Li, and Ms. Paola Zanella of the Aerospace Systems Design Lab for their support, expertise, and feedback in regards to this project. The authors would also like to thank Mr. Ian Redhead from MCI and Ms. Sandra Lancaster from DFW for providing the unique case-studies and their constant feedback on the project. The authors would like to thank Ms. Nancy Young from Airlines for America for providing feedback from the perspective of the airlines, Dr. James Hileman and Ms. Rebecca Cointin from the FAA for providing the FAA perspective and insight, and Mr. Ambrose Clay and Mr. Gary Young from the city of College Park for their feedback.

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